Absorber cryo and safety design

MUCOOL – MICE meeting

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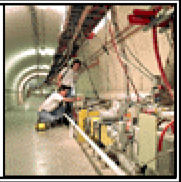
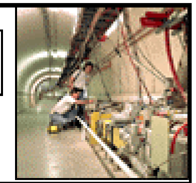
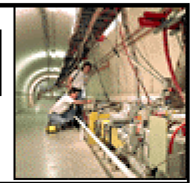




Absorber cryo and safety design

- Environment of the LH2 absorber test facility (cf Barry's talk)
- LH2 Absorber system and cryogenic loop @ test facility
- Safety and Cryo-design
- Conclusion and further works



Environment of the test (cf Barry's talk)

- **Helium refrigeration schematic**

  <u>How can we provide the refrigeration power ?</u>

  => Tevatron cooling system like

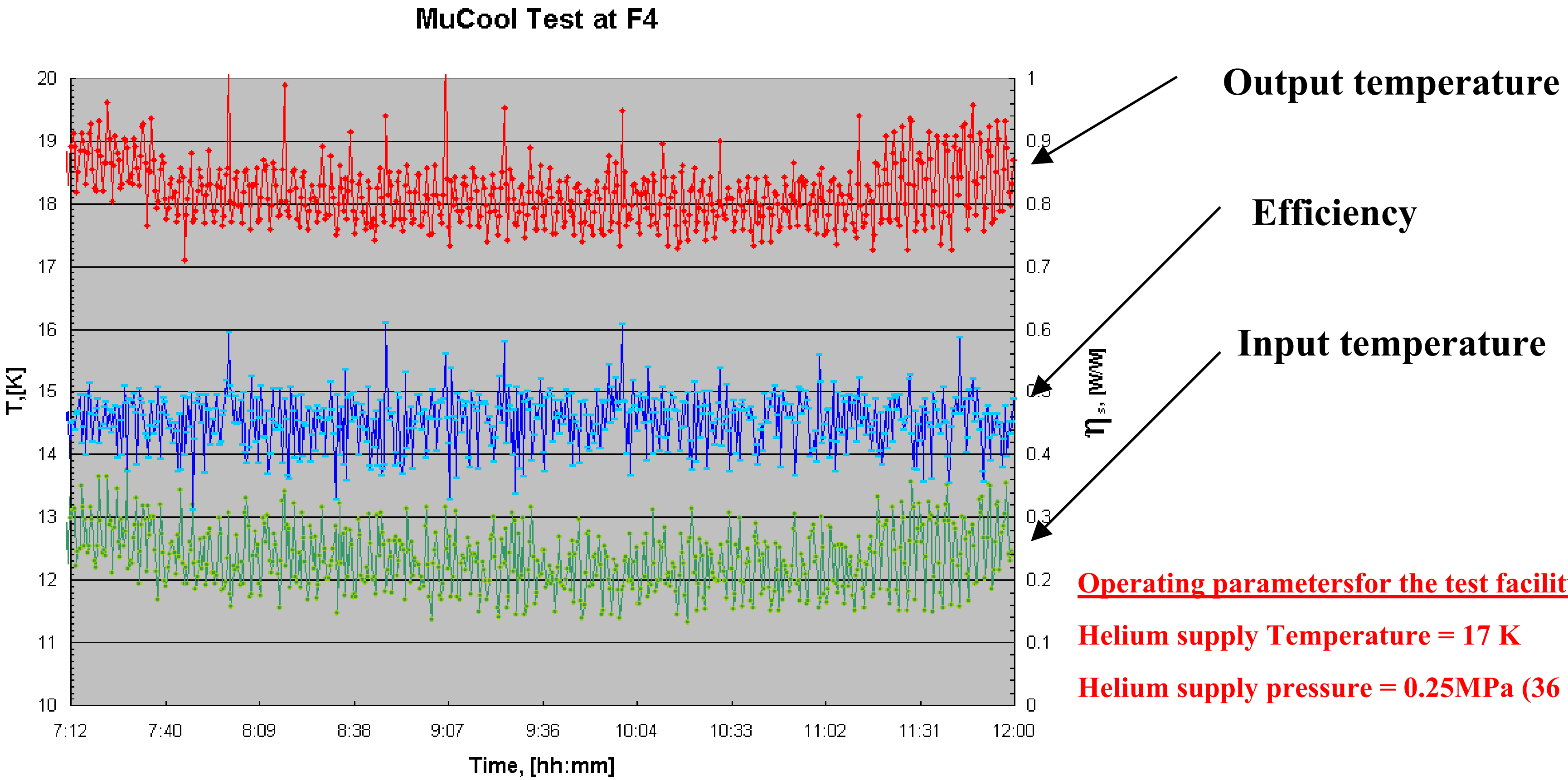
  <u>How much could be provided ?</u>

  => Up to 500 W at 20 K

- **Hydrogen refrigeration loop schematic**

Cryo-test during a Tevatron shut-down period

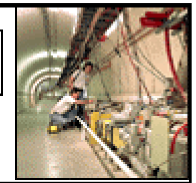
Goal of the test: stability measurement for running at 14 K instead of 5 K



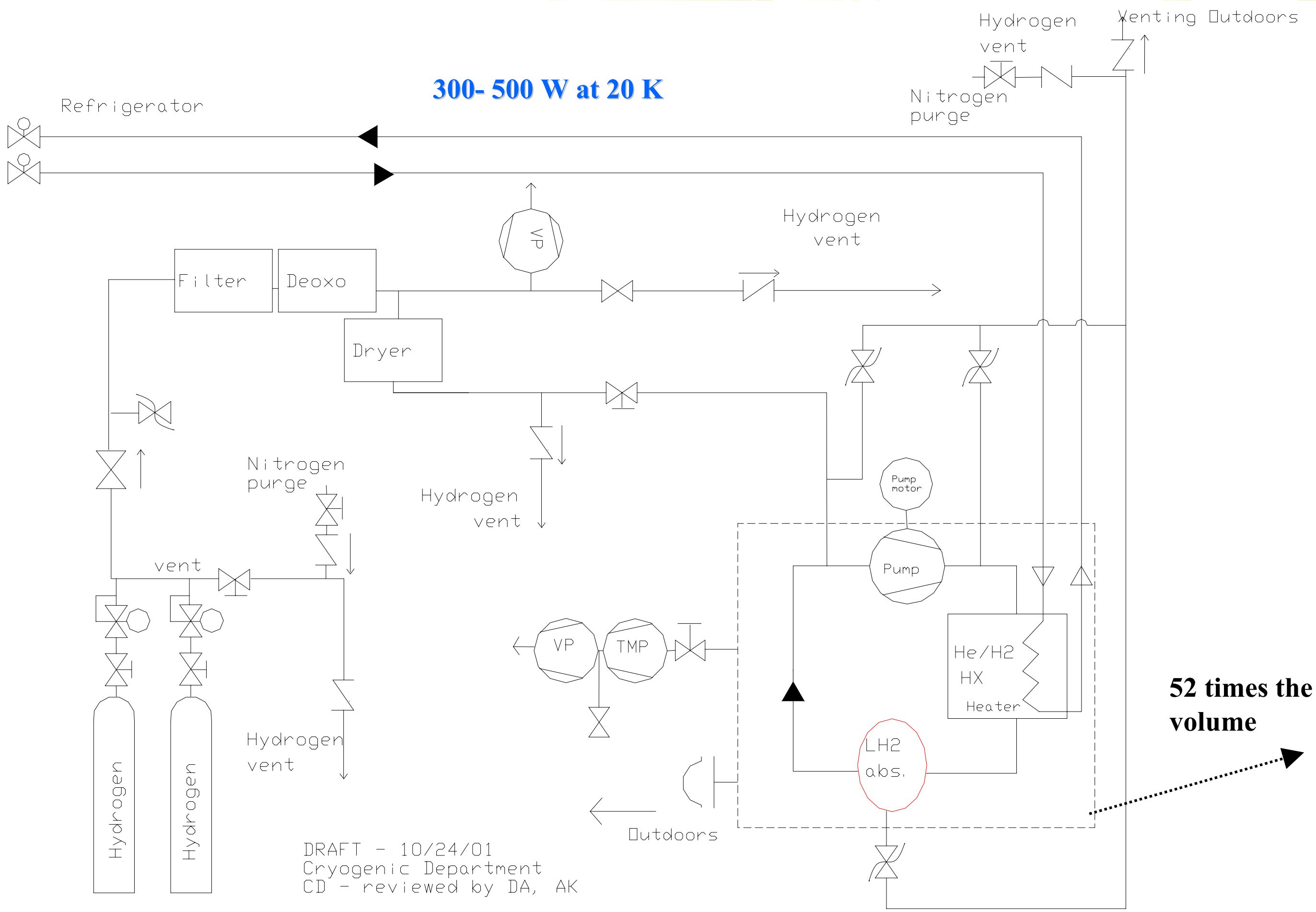
Operating parametersfor the test facility:

Helium supply Temperature = 17 K

Helium supply pressure = 0.25MPa (36 psi)



Hydrogen refrigeration loop schematic



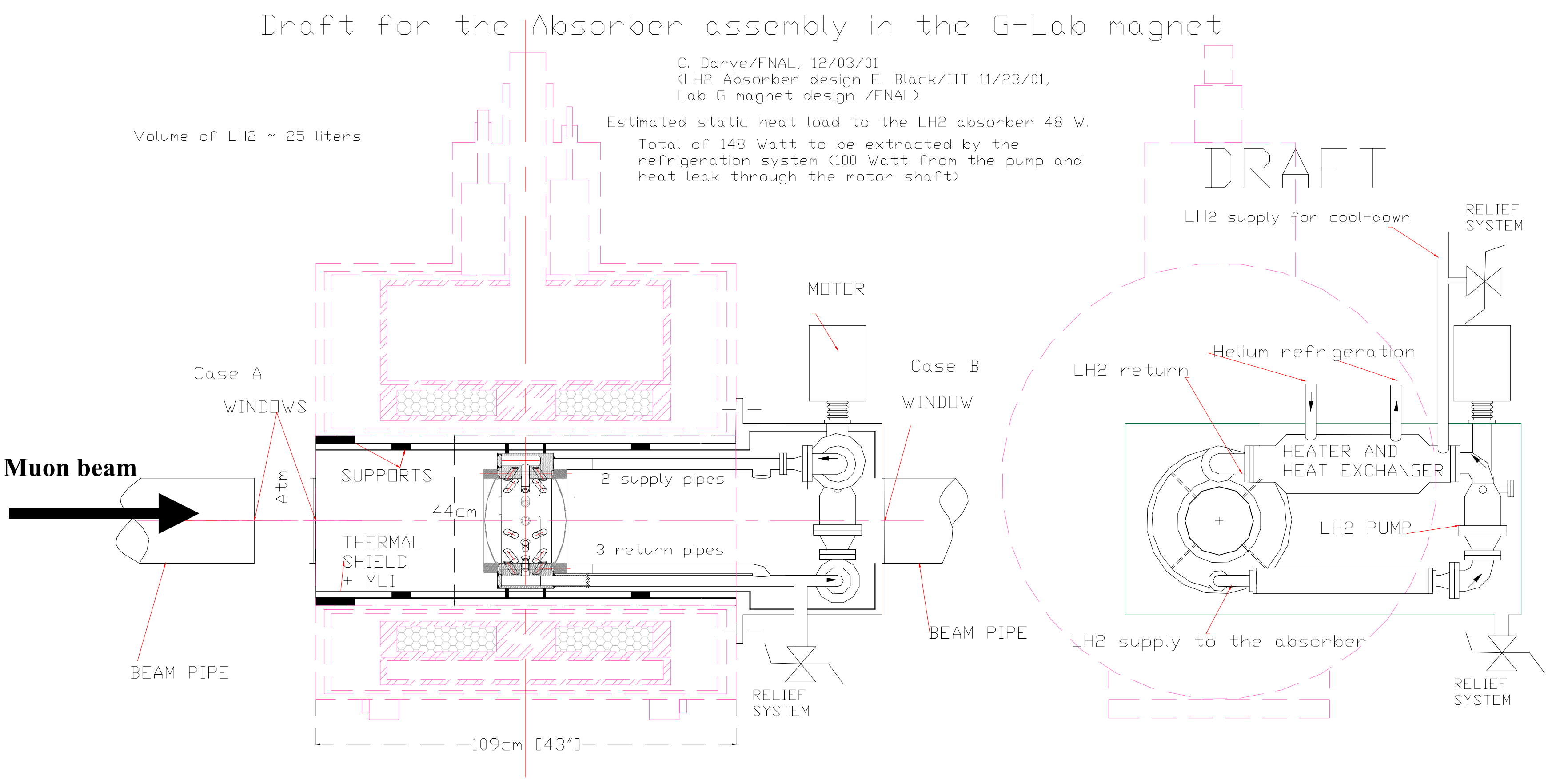
52 times the LH2 volume

LH2 Absorber system and cryogenic loop @ test facility

Components:

- Cryostat
- LH2 Absorber
- LH2 pump
- Helium/Hydrogen heat exchanger
- Heat load to the cryostat
- Pressure drop

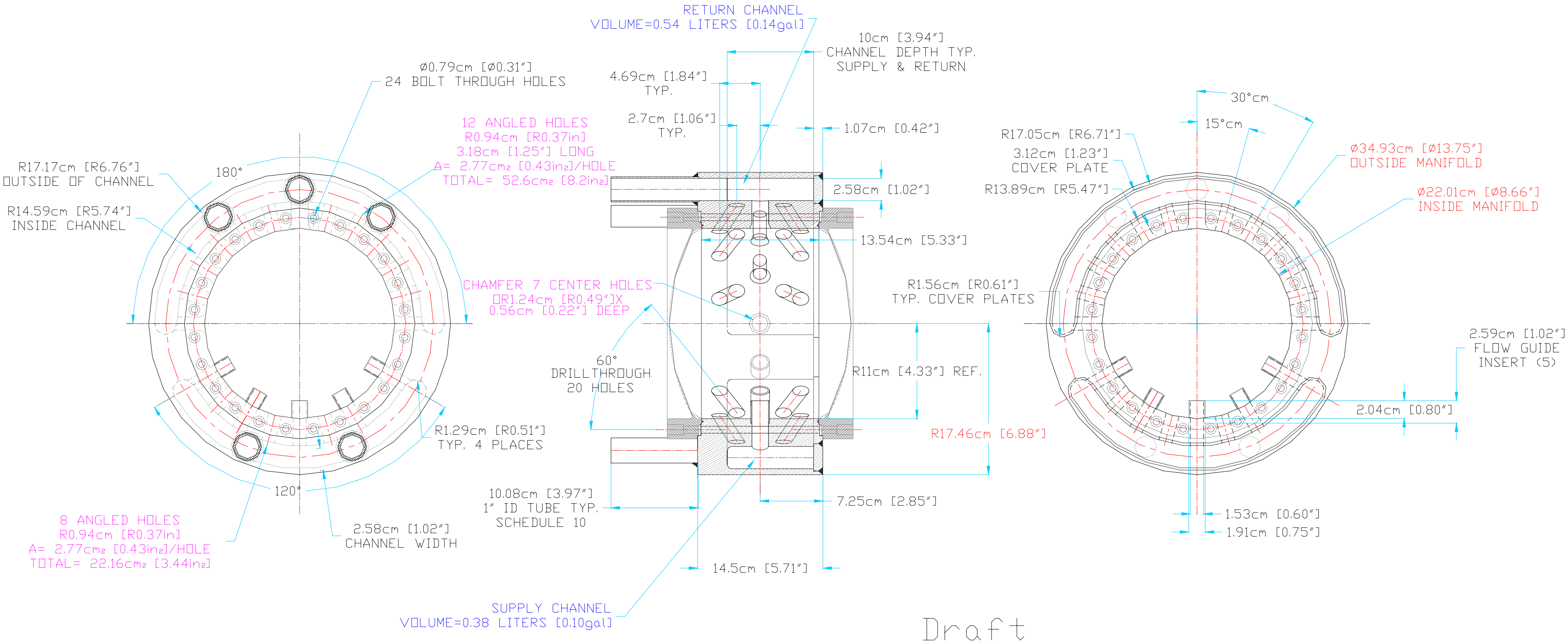
LH2 Absorber system and cryogenic loop @ test facility



LH2 Absorber system and cryogenic loop @ test facility

- Cryostat
  - Stainless steel vacuum vessel
  - Thermal shield actively cooled by nitrogen
  - Super insulation (30 layers of MLI on the thermal shield)
  - G10 support spider
  - Pressure safety relief valves
- Absorber (2 windows + manifold)
  - 6 liters of LH_2
  - Supporting system (mechanical support, insulation, alignment..)
  - Supply and return channels connections

LH2 Absorber system and cryogenic loop @ test facility



R 11 CM WINDOW MANIFOLD DETAIL

E.L.Black/IIT 5/22/2001
GEN.REV. 11/23/2001

LH2 pump

Spare pump from SAMPLE

- Reference: “Nuclear Instruments and methods in physics research”, by E.J. Beise et al.

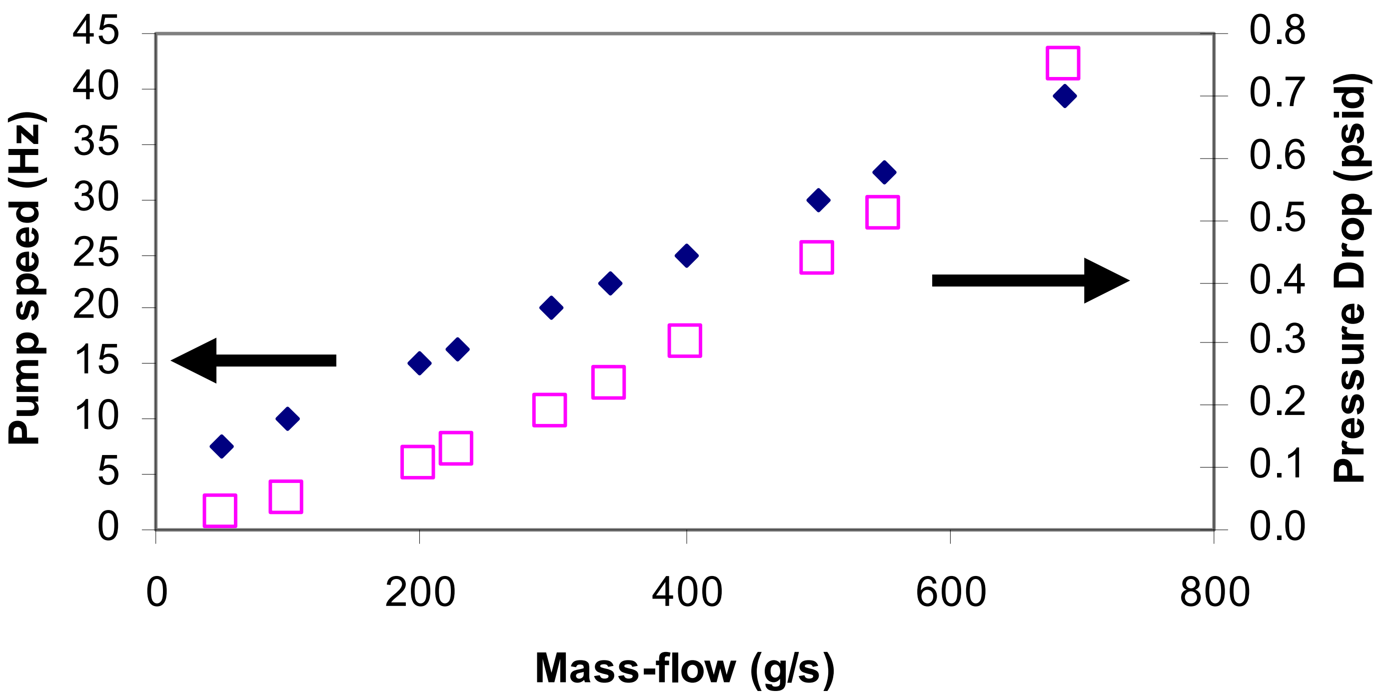
Characteristics:

- Controlled by AC motor @ RT (2 HP)
- Circulating pump (up to 550 g/s)
- Expected pump efficiency~ 50% (cf. SAMPLE test)
- Heat load α (fluid velocity)^3 and Heat load α (pump speed)^3

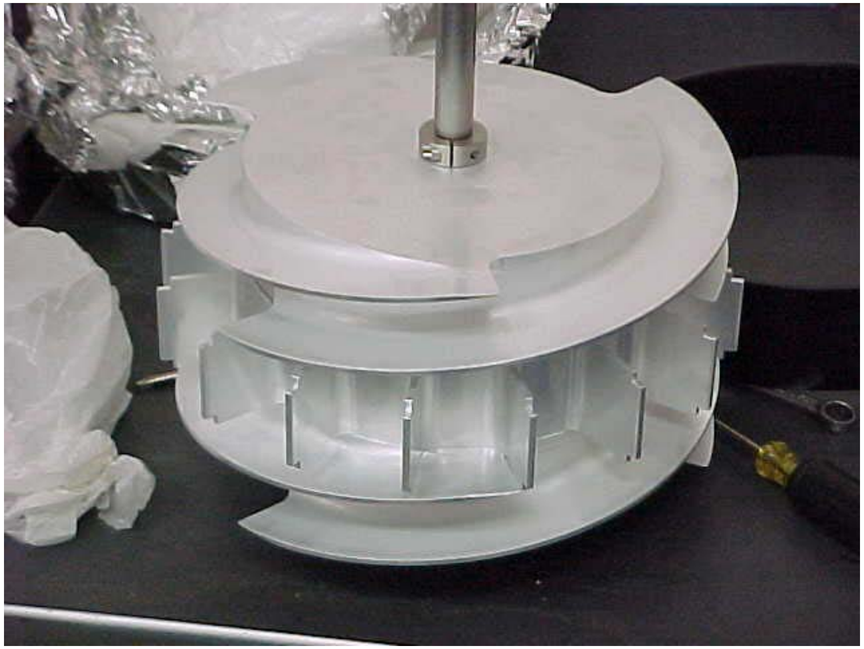
<100 Watt from the pump and heat leak through the motor shaft

LH2 pump

Characteristics of the current LH2 pump



E158 LH2 pump



Note: Our pump is 1.5 time smaller than the E158 one

Heat Exchanger

The HX is sized to extract up to 1 kW

Helium/LH2 co-current flow

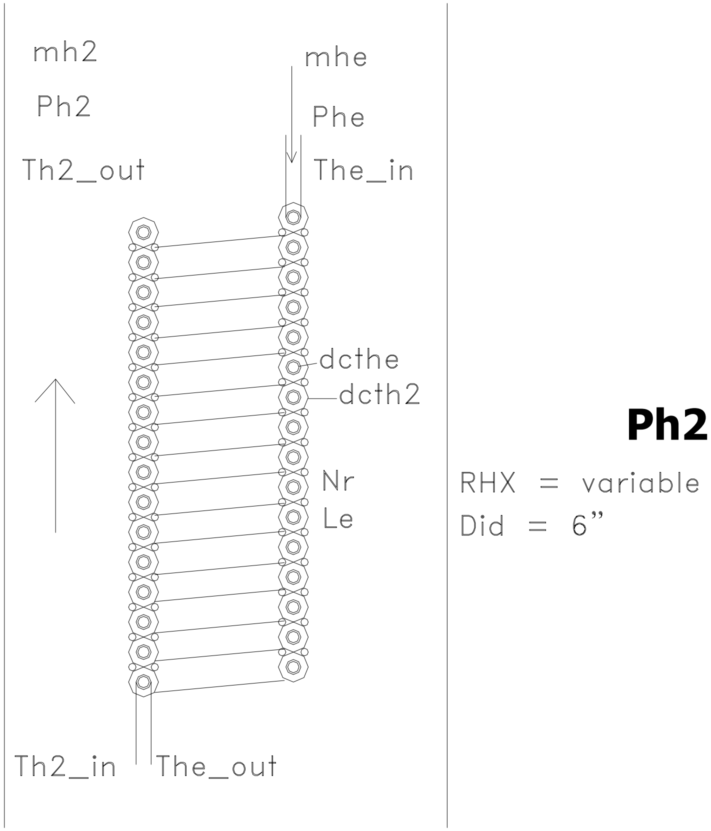
<u>Helium properties:</u>

Thein = 14 K

Theout=16.5 K

Phe=0.135 MPa (19.6psi)

mhe=75 g/s



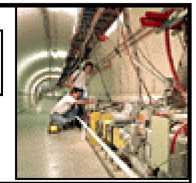
<u>Hydrogen properties:</u>

Th2in=17.3 K

Th2out=17 K

Ph2=0.121 MPa (17.5 psi)

mh2=420 g/s



Heat Exchanger

The_in
The_out
Phe_in
mhe

Helium parameters

Th2in
Th2out
Ph2
mh2

Hydrogen parameters

Q
dct
th
DHX

Geometric parameters

Number of iteration i

Hepak&
Gaspak

ρ_h2(T)
μ_h2(T)
K_h2 (T)
Cp_h2 (T)
h_h2(T)

ρ_he(T)
μ_he(T)
K_he (T)
Cp_he (T)
h_he(T)

$$Tcti = \frac{(The_i \bullet h\_he_i) + (Th2_i \bullet h\_h2_i)}{(h\_he_i + h\_h2_i)}$$

Surface HX
Length HX vs. dct
Pressure drop / helium

Pressure drop / hydrogen
Number of spire vs. DHX

Cal. for each T. iteration

Velocity of helium in cooling tube
Velocity of hydrogen in HX
Reynolds number / He and H2
Prandtl number / He and H2
Nusselt number / He and H2
Convection coeff / He and H2

Wall temp. on He and H2 side

To compared with Q

Qconduction
Qconvection on He and H2 side
H2 cooling capacity
He cooling capacity

Heat Exchanger

⌘ **Solution**

Inner diam. cooling tube = 0.623″=15.8 mm
Thickness = 0.032″=0.81 mm
Outer Shell diameter = 6″= 152.4 mm
Length including the heater = 20″= 508 mm

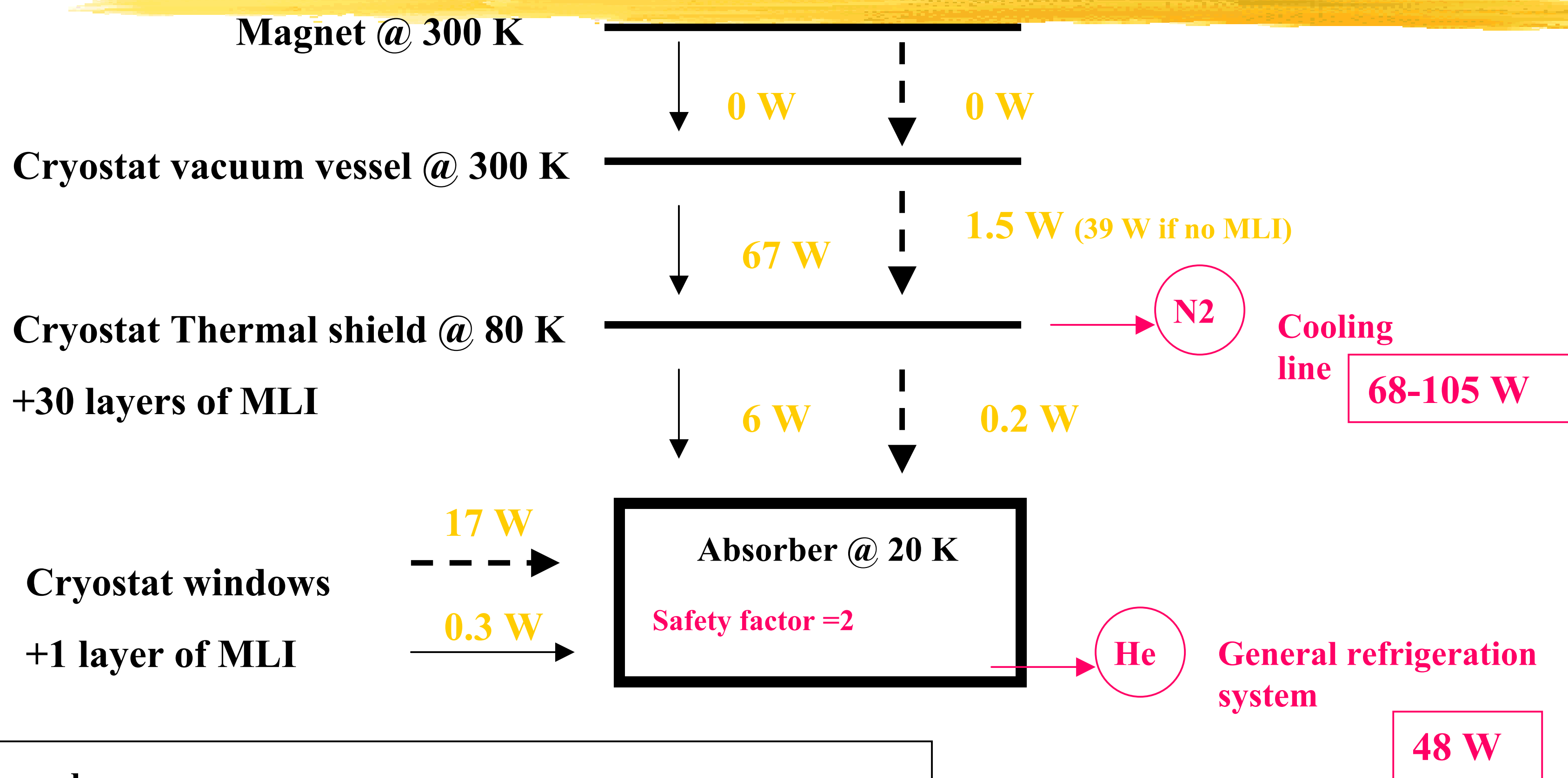
1. **Surface of the heat exchange** = 0.359 m^2
2. **Length for dcthe = 0.623 " (15.82 mm),** Le= 7.22 m
3. **If DHX=4.5 " and dct = 0.623 " than,** Nr = 22 spires and Le2=7.46 m
4. **Pressure drop on the LH2 side,** droph2= 2.1E-3 psi
5. **Pressure drop in Helium side,** drophe= 3.9 psi

Heat load from ambient to absorber temperature level

The refrigeration power will be distributed between the beam load and the static heat load

- Determination of the heat load to the Absorber
- Conduction through the G10 support (VV → TS → Abs)
- Radiation and Conduction in residual gas, MLI (VV → TS → Abs)
- Radiation (windows → Abs)

Heat load from ambient to absorber temperature level



Legend:

- Heat transfer by conduction through the G10 support (solid arrow)
- Heat transfer by radiation and through MLI (dashed arrow)

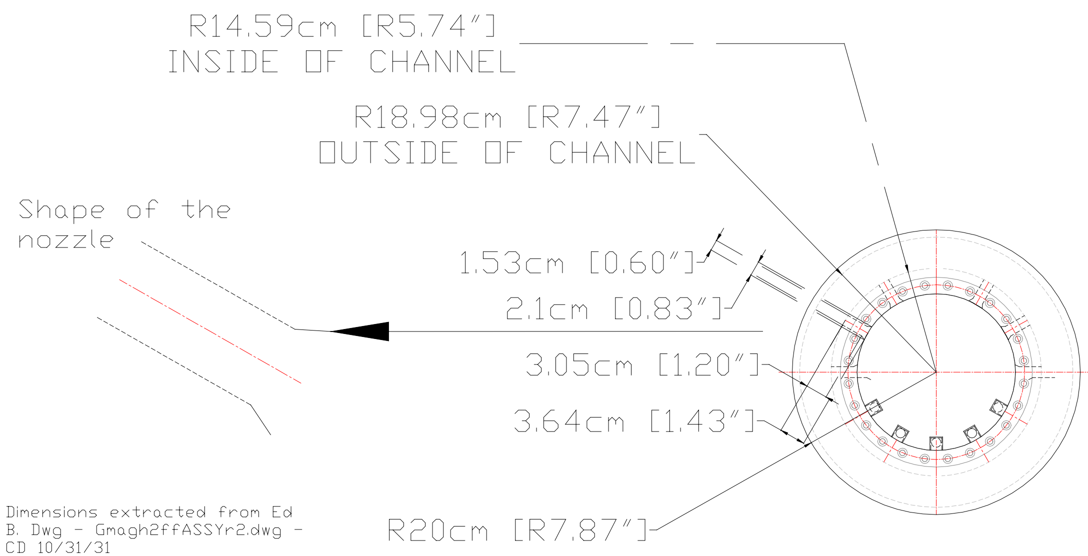
Pressure drop in the LH2 loop

- 1D analysis of the total pressure drop at the pump inlet and outlet
- Hydrogen mass flow: 550 g/s
- Pressure/temperature of Hydrogen: 1.7b/17K

<u>Absorber flow circuit:</u>

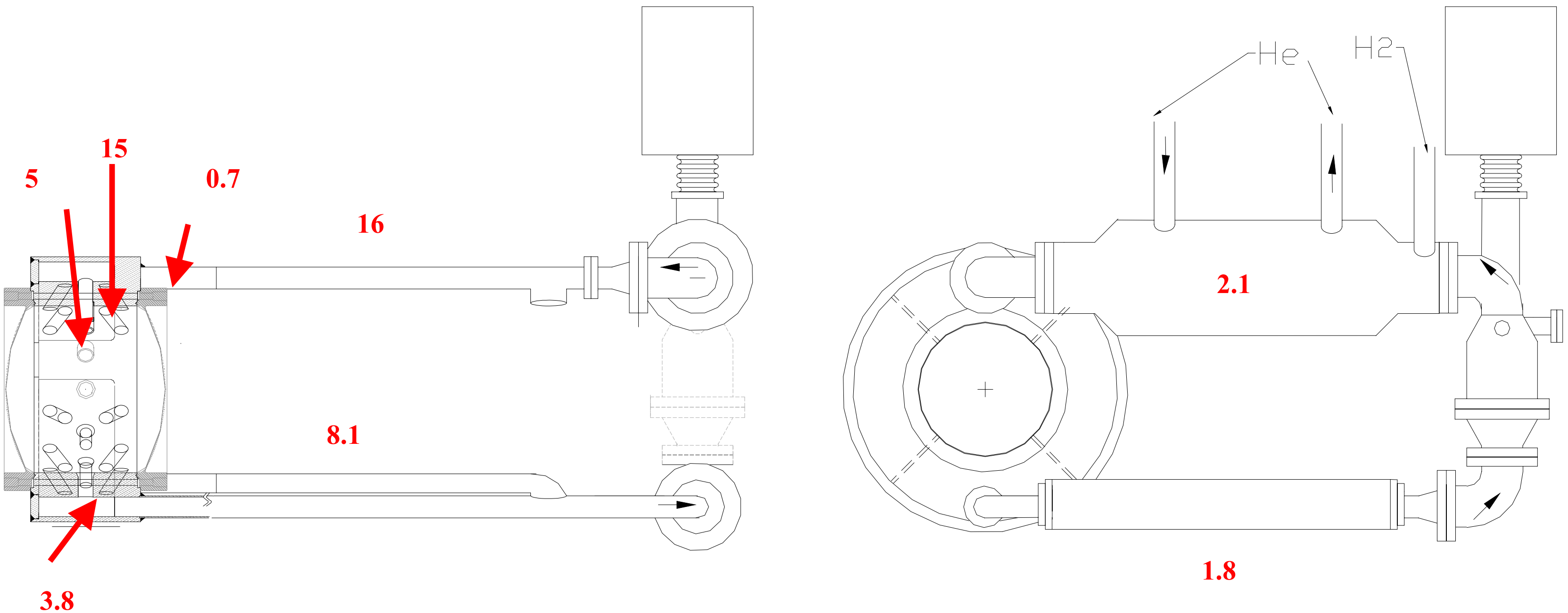
Supply: 13 nozzles

Return: 19 nozzles

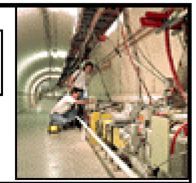


Pressure drop

Map of the pressure drop: Delta-P (10^{-3} psi)



C/C: The total Pressure drop through the system is 52.5×10^{-3} psi (356 Pa)



Safety and Cryo-design

The design of the LH2 absorber cryo system must meet the requirements of the report "Guidelines for the Design, Fabrication, Testing, Installation and Operation of LH2 Targets – 20 May 1997" by Del Allspach

Test facility

LH2 Absorber

- Aluminum 6061 T6 and series 300 Stainless-steel
- Design for a MAWP of 25 psid..
- PSRV sized to relieve at 10 psig (25 psid)

Vacuum vessel

- Aluminum 6061 T6 and series 300 Stainless-steel
- Stress analysis for mechanical and thermal loads
- Design for a MAWP of at least 15 psig internal
- PSRV sized to relieve less than 15 psig (30 psia)

Safety and Cryo-design

The Pressure safety valves

Sized for the cases of Hydrogen boil-off in vacuum failure (no fire consideration)

- LH2 loop => Two pressure relieve valves (Anderson Greenwood type) located before and after the LH2 pump

- Vacuum vessel => two parallel plates and a check valve in series with a safety controlled valve

Comments

- Electrical risk– Follow guidelines – NEC Requirements for H2
- Second containment vessel avoided if possible.
- Hydrogen vent

Vacuum vessel - Cryostat window thickness

- Parameters that influence the mechanical choice of the window:
  - Pressure (value, direction) => 2 Configurations
  - Shape
  - Material
  - Diameter

- Pressure configurations

Case A) two windows to be separated by the atmosphere

Beam pipe vacuum----wind#1----atm----wind#2----Cryostat vacuum => P=15 psid
twice the thickness

Case B) one window in between both vacuums

Beam pipe vacuum----wind#1----Cryostat vacuum => P=30 psid

Vacuum vessel - Cryostat window thickness

⌘ Shape

The maximum allowable stress in the window should be the smaller of:

Su x 0.4 or Sy x 2/3

<u>Flat plate</u>

$$\mathrm{Sigma} = E \cdot \frac{tk^2}{a^2} \cdot \left[K3 \cdot \frac{y}{tk} + K4 \cdot \left(\frac{y}{tk}\right)^2 \right] \qquad K3 = 4.286$$

$$K4 := 0.976$$

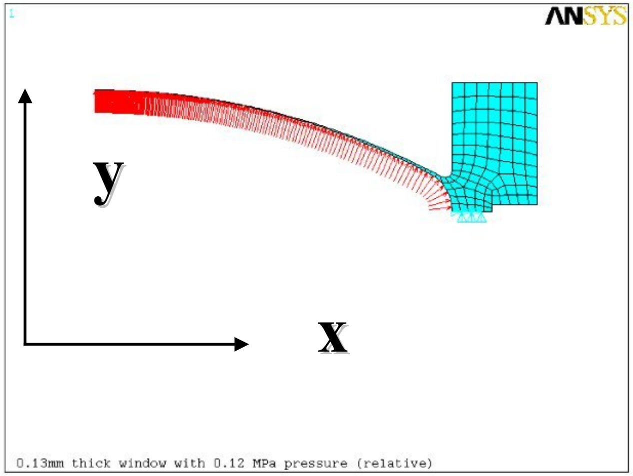
$$f(y) := K1 \cdot \frac{y}{tk} + K2 \cdot \left(\frac{y}{tk}\right)^3 - q \cdot \frac{a^4}{E \cdot tk^4}$$

$$K1 := \frac{5.33}{\left(1 - v^2\right)}$$

$$K2 := \frac{2.6}{\left(1 - v^2\right)}$$

<u>Torispherical</u>

Finite element analysis =>



Vacuum vessel - Cryostat window thickness

⌘ Materials (need exact material physical properties)

Materials	E (GPa/10^6 psi)	Ultimate stress (MPa/ksi)	Yield stress (MPa/ksi)
Titanium – Ti 15-3-3	92.4/13.40	835.0/121.10	737.7/107.0
Aluminum – 6061 T6	68.0/9.86	312.0/45.25	282.0/40.9
Beryllium – S-200E	251.0/36.41	485.4/70.40	297.9/43.2

⌘ Diameter

Even if the muon beam diameter can vary along the cooling channel, the first containment window should keep the same diameter

→ D= 22 cm (8.66”)

Cryostat window thickness – Potential solutions 22-cm window

Flat plate thickness (mm)

Materials	W/ Atmosphere interface 2 windows, 15 psid	W/o Atmosphere interface 1 window, 30 psid
Titanium – Ti 15-3-3	0.489	0.775
Aluminum – 6061 T6	5.280	3.887
Beryllium – S-200E	4.360	3.080

Torispherical thickness (mm)

Materials	W/ Atmosphere interface 2 windows, 15 psid	W/o Atmosphere interface 1 window, 30 psid
Aluminum – 6061 T6	0.304	0.260

Conclusions

The feasibility of the LH2 Absorber cryo. system has been studied, conceptual designs are proposed. Safety issues still need to be finalized.

- ✓ Preparation of the safety documentation / Safety Hazard Analysis
- ✓ Committee and review

More results can be found at:

http://www-bdcryo.fnal.gov/darve/mu_cool/mu_cool_HP.htm